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SAMOSA - ScAnner Micro-Onde pour la Sécurisation des Aéroports

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Résumé – Des événements récents ont montré qu'un terroriste déterminé était encore capable d'introduire à bord d'un avion de ligne des matières explosives pour tenter de le faire exploser en vol. Le risque d'attentat à l'explosif perpétré par un passager kamikaze dans la cabine d'un avion est bel et bien réel. Le projet SAMOSA s'inscrit dans ce contexte ; son objectif est de développer un système de détection basé sur des technologies d'imagerie Radiofréquence permettant la détection d'explosif embarqué par un passager du transport aérien, que cet explosif soit situé au contact du corps ou voire implanté de façon sous-cutanée dans le corps. Il nécessite de caractériser les propriétés diélectriques des explosifs constituant la menace la plus crédible. Cette nouvelle technologie présenterait de nombreux avantages par rapport à l'existant. Elle permettrait notamment de détecter des explosifs sur le corps humain sans dévoiler l'anatomie intime des passagers, principal frein aujourd'hui à l'acceptabilité des technologies en cours de déploiement. Ce projet propose de développer une nouvelle brique technologique qui pourra être utilisée sur le poste d'inspection filtrage du futur pour améliorer le niveau de réponse à cette menace. Ce projet s'inscrit dans la tendance actuelle des développements de technologies d'imagerie avancées. De plus, en abordant les aspects sociaux, éthiques et juridiques de ce type d'appareil, le projet apportera un éclairage nouveau sur la conception des outils de sécurité civile et leur intégration dans la société civile afin d'en améliorer son acceptabilité.

Abstract – Recent events have shown that a determined terrorist could be able to board in a plane with explosive materials to blow up the plane during the flight. The risk that a kamikaze perpetrates a terrorist attack in the cabin of a plane is undeniably real. SAMOSA project falls within this context. Its objective is to develop a new detection system, based on microwave imaging technology, allowing the detection of embedded explosive on a flight passenger. The explosive could be carried closed to the body or subcutaneous. This new technology has many advantages compared to the existing one. It allows detecting explosives located on human body without revealing the intimate anatomy of passengers, this point being the main problem with the current deployed technology. The project suggests developing an advanced technology which could be used during the filtering and inspection boarding phases to improve the results related to this threat. In addition, the project is in the current tendency of developing advanced vision technology. However, addressing social ethic and juridical aspects of this kind of systems, the project will bring a new lighting about civil security tools and their integration in civil society.

1. Introduction

1.1 An exhaustive approach

The objective of this innovative project is to develop a new detection system, based on microwave imaging technology, allowing the detection of embedded explosive on a flight passenger.

The exhaustive approach is very interesting and innovative: in parallel of the technical activities, are studied the acceptability and interacceptability aspects, the legal, ethical, health and societal aspects.

1.2 Consortium

Seven partners with various complementary competencies joined the consortium to allow this project presents an innovative and exhaustive approach of the activities (see Fig.1)

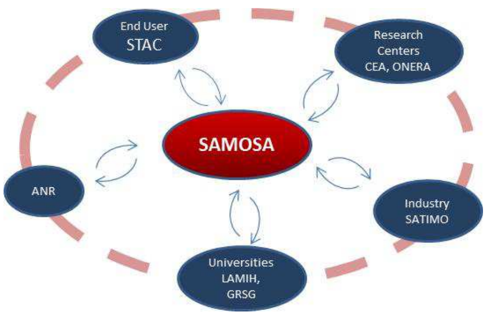

FIG. 1 : SAMOSA consortium.

- SATIMO is specialized in the design and development of antenna measurement, industrial control and tomographic imaging systems which are based on multi-sensors fast technologies to measure in quasi real time. SATIMO brings its expertise in RF systems development, production and integration. This project will bring a potential innovative product, a new market and a best knowledge of customer needs.

- The team of the CEA which is concerned by the project is expert in the security, terrorist threats and explosives. Moreover, its powerful calculators are used during the project to make electromagnetic simulations of whole people. Results are used to develop imaging algorithms.

- The concerned entity of the ONERA is specialized in radar signals, electromagnetic simulations, signal analysis, particularly in imaging algorithms.

  These two research centers bring to the project their scientific and technical knowledge and see in this project the opportunity to have new valorizations of their expertise on new markets.

- The STAC (Service Technique de l'Aviation Civile) represents the end user of the innovative detection scanner for airport security. The STAC brings to the project its operational knowledge of airport environment.

- The LAMIH-PERCOTEC laboratory is specialized in psychological and acceptability aspects of the use of the scanner for the passenger and for the operator. The LAMIH-ASHM laboratory is specialized in the multi-criterion interacceptability aspects.

- The "Groupe de Recherche sur la Sécurité et la Gouvernance" (GRSG) brings its expertise for the legal, ethical, health and societal aspects.

  These two research laboratories bring to the project their experience in the acceptability analysis as well as in the legal, ethical and health aspects. Through this project, they will work on new research domains and new valorization of their knowledge.

- ANR (Agence Nationale de la Recherche) is financing the project and gives the objectives and coordination tools. The project is presenting an improvement of the security at the airports and participates to the synergy between the French actors.

1.3 Organization and progress of the project

This project is financed by the ANR within the CSOSG 2010 program. Its initial duration is of 36 months as from March, 2011, but it has been extended of one year. The kick-off meeting took place on April 11th, 2011. The end of the project will take place on February 28th, 2015. The project is divided into 8 main tasks. Technical meetings take place regularly between the actors of the concerned tasks (see the Fig. 2). The project is punctuated by the biannual meetings and by associated deliverables.

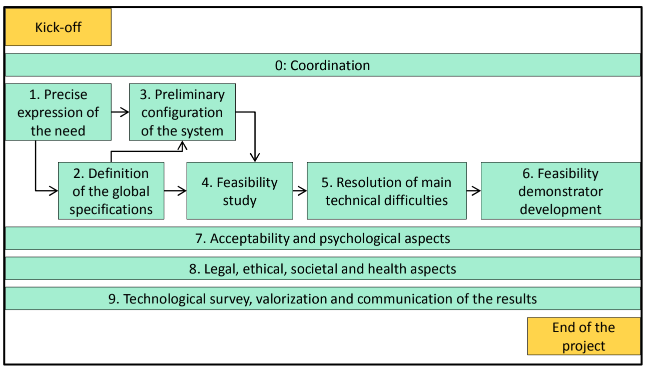

FIG. 2 : Main phases of the project.

Previously, the context of the project and the main objectives had been presented [1], then the definition of the global specifications, the preliminary configuration and the feasibility study [2], and finally the acceptability of security scanners in French airports [3].

This first part of the paper is focused on the main results of the latest studies for legal, ethical and health aspects, as well as for the psychological aspects with the doctrine for the employment of disciplines. The second part is presenting the technical developments.

2. Legal, ethical, health and psychology aspects as regards the use of security scanners.

2.1 A huge piece of European legislation

Although since 2001 a lot of measures supplementing the previous security standards have been added, the International Civil Aviation Organisation didn't rule on security scanners and let each country choose its own regulation. In the United States, it is the TSA Transport Security Administration that rules on this issue. In the European Union, successive regulations were introduced: Regulation (EU n° 2320/2002) in 2002, replaced in 2008 by Regulation (EU) n°300/2008 and completed in April 2009 by Regulation (EU) n° 272/2009. The Commission Regulation (EU) n°185/2010 modified the text on March 2010. Regulation (EU) n°1147/2011 of 11 November 2011 is the last version; it implements the common basic standards as regards the use of security scanners at EU airports.

Security scanners shall also be deployed and used in compliance with national and European regulations on the minimum health and safety requirements regarding the exposure of the public and workers to electromagnetic fields. Concerning the exposure of the general public there is the Council Recommendation 1999/519/EC of 12 July 1999. This text is transposed in French law to the application decree n°2002-775 of 3 May 2002. For the exposure of workers, the European Parliament and the Council of 29 April 2004 took a first directive: 2004/40/EC, but the transposition has been delayed by stakeholders, in particular those from the medical community. Finally it was repealed and replaced by Directive 2013/35/EU of 26 June 2013. Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 1 June 2016. French ANSES already published a "recommendation" for security scanners.

2.2 A protocol in accordance with legislation for SAMOSA

The number and the variety of these regulations need to be scrutinized as to their real force and at the eventual interference in case of confrontation. European legislation is compulsory and the common bases are minimum requirements. Each Member State is allowed to legislate beyond those minimum requirements. The analysis of the European and national legislation allows to establish a six points protocol for SAMOSA including image rights, respect for human dignity and for private and family life. These points are: a separate human reviewer; the use of an avatar; no storage nor copy of the data and images; previous information of the passenger; possibility to choose the gender of the reviewer; possibility to opt out the security scanner control and choose an alternative screening method including at least a hand search.

In France, the matter of human dignity needs further specific developments. The hypertrophy of the topic in French law introduces multiple confusions between human rights and individual liberties. The protocol established for SAMOSA protects the public from any invasion of privacy not excluding however different individual feelings. Such feelings could be a problem and that should be prevented.

2.3 Health problems

The European legislation covers all known direct biophysical effects and indirect effects caused by electromagnetic fields but there are still a lot of no well-established risks. The minimum health requirements regarding the exposure to electromagnetic fields changed since the 2000s. The thermal effects were the most important effects taken into account. Now various effects are mentioned as transient symptoms, such as vertigo or phosphenes, or the interference with medical electronic equipment and device. The effects on young children and long-term effects are not yet covered but are studied. Even electrosensitivity problems begin to be taken into account by the scientific community. The precautionary principle must be revised.

2.4 Area of research

In terms of ethic, politics and sociology: semi-structured interviews are under process to determinate more accurately the real feelings concerning airport security measures and more precisely security scanners. The role of the State, the respect for freedoms and human dignity, the possible invasion of privacy, the matter of health and the importance of information are examined.

In terms of health: additional approaches are planned. The research laboratory XLIM from Limoges University will calculate by numerical simulation the penetration of human tissue by electromagnetic waves. Another approach, this time on the cellular level, will be asked to the cytogeneticist Catherine Yardin who worked on aneuploidy for cells exposed to electromagnetic fields. An interview of the "Collectif des Electrosensibles de France » is planned concerning the electrosensitivity.

2.5 Psychology aspects

A survey on the acceptability of security scanners was conducted in France in July 2012 with a sample of 458 air travelers. The majority of the respondents trusted security scanners to detect hidden explosives and would consent to undergo scanning if such scanners were implemented at French airports. The results also show a possible gap between public and experts. Indeed, the great majority of the respondents perceived breaches of neither their private life nor their freedoms or human dignity. The single significant difference regarding the respondent profile was that the women tended to be more sensitive to the breach of private life than the men were. Moreover, a great majority of the respondents disagreed with the statement that the visualization by a security officer of an image of their body would be embarrassing; nevertheless, it must be emphasized that perceived embarrassment occurred less frequently with an avatar than with an image of the body of the passenger. On the other hand, a majority of respondents (64.8 percent) disagreed with the statement that passing through a security scanner would have an effect on their health, whereas 27.4 percent agreed and 7.8 percent had no opinion. To conclude, the survey has showed a possible compliance of the public to social norms regarding security technologies: a very strong majority of the respondents (91.6 %) agreed with the statement that passing through a security scanner was normal in the fight against insecurity.

3. Doctrine for the Employment of Disciplines

In establishing a Client-Analyst relationship, the concepts of decision aiding [4] facilitates appropriate and timely investigations and productions of recommendations in a given reality. The Decision Aiding Process (DAP) approach [5] tackles decision aiding as a decisional process in four phases [6]: Problem Situation, Problem Formulation, Evaluation Model and Final Recommendation.

In superposing DAP onto a checkpoint process for the four phases (Welcoming passengers, Preparation, Searching and Filtering), the SAMOSA project is better able to take into consideration human factors to improve the possibilities of a checkpoint. This enables a better preparation of how to integrate equipment.

In this light, the different studies of human factors and their integration in the technical design process of the equipment (tasks t2 to t6) are linked up in a « Doctrine for the Employment of Disciplines » (task t7.2), based on the principals of the Theory of social choice [7], in order to improve the efficiency and combination of different domains. Prior to the design of the equipment, the domains of cognitive psychology (task t7.1) and the legal and political sciences (task t8) have been studying the issue of safety acceptability concerning passengers as well as the issues of ethics and dignity from a societal point of view. To extend the design activities, the management of the project (task t0) was enriched by several concepts taken from the management sciences, notably quality management, social responsibility, marketing and business development. To develop the equipment in a minimal amount of time, the Information and Communication Sciences highlighted the informational elements to be communicated to different stakeholders via the concept of decisional sensemaking. To operationalize the recommendations taken from the different disciplines, two Client-Analyst relationships are being defined to clarify the questions examined in the Project:

- What is a more « permanently » stabilised definition of the needs of the checkpoint (task t1) from the point of view of the Civil Aviation Authoring as the final user?

- What is a more precise definition of scenarios concerning target realities in order to improve the design robustness by the project leader, SATIMO?

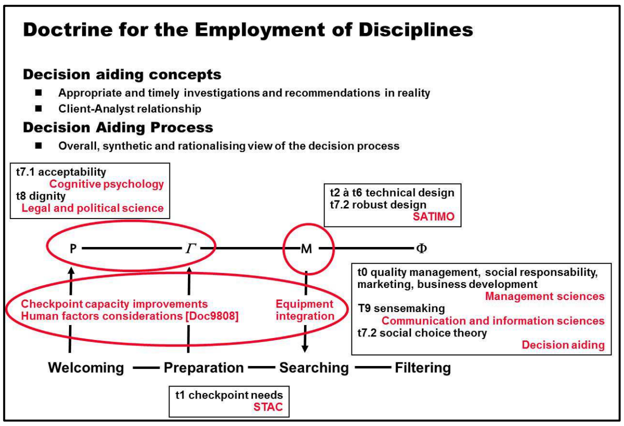

FIG. 3: Doctrine for the Employment of Disciplines.

4. Technical aspects

4.1 Preliminary prototype and first results

To solve the first technical difficulties and show the feasibility of the system, a preliminary prototype has been made. A mechanical system equipped with two horns allows scanning a mannequin carrying some targets. The first horn is used in emission and the second one in reception. The two horns can be moved vertically and the human model can be rotated to allow a 3D scanning (see Fig. 4). First imaging tests are performed on a plastic mannequin filled with water and focused on the 0.8-12 GHz frequency range.

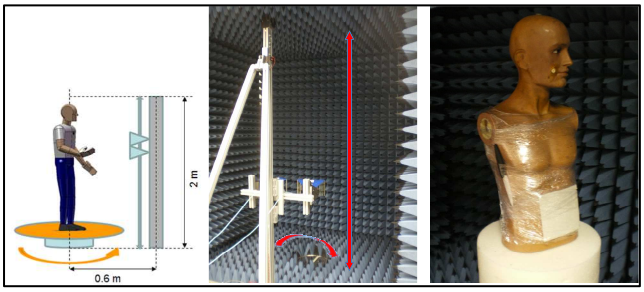

FIG. 4: Preliminary prototype.

A first type of imaging algorithm is used to analyze the experiments. The Fig.5 shows the principle of this algorithm.

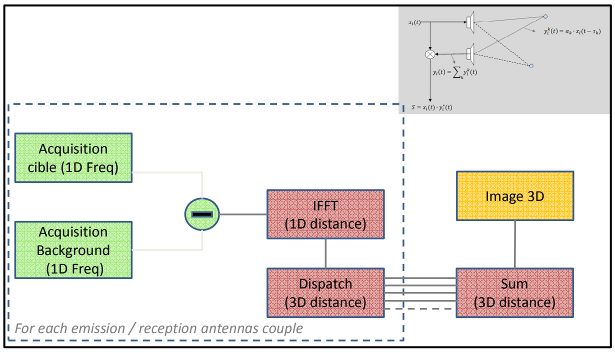

FIG. 5: Imaging algorithm.

A lot of configurations have been tested. The mannequin is scanned with and without carrying target. The targets are different in shape and material. They are representative and simulate guns or explosives.

From the numerous tests led, we can see that some targets are easier to detect, even without subtracting the background, than others. This is the case if the target is located on the side of the mannequin : the image resulting from the imaging algorithm, without subtracting the background, allows detecting it. For example, the Fig.6 shows the results when the target is a metallic gun located on the side of the mannequin. The photography presents the test configuration; the first image is obtained for the mannequin alone; the second image is obtained for the mannequin carrying the gun. The target appears on the image.

Some targets are more difficult to detect, in particular when the target is located against the trunk of the mannequin. In this case, the imaging algorithm is not capable to highlight the target without subtracting the background. It can be explained by the fact that the coupling of the mannequin and the target is more important in this case than when the target is located on the side of the mannequin. The Fig.7 shows the case of a metallic ball located on the trunk of the mannequin. The photography shows the test configuration; the first image is obtained for the mannequin alone; the second one for the mannequin with the metallic ball; the third image is obtained after subtracting the signal of the mannequin alone from the signal of the mannequin with the ball. This subtraction allows highlighting the target.

Of course, in a realistic configuration, it won't be possible to scan a person without an eventual target (background) and then to subtract it from the next acquisitions. But the feasibility of the detection has been demonstrated and more complex algorithms which do not require the subtraction of the background have now to be investigated.

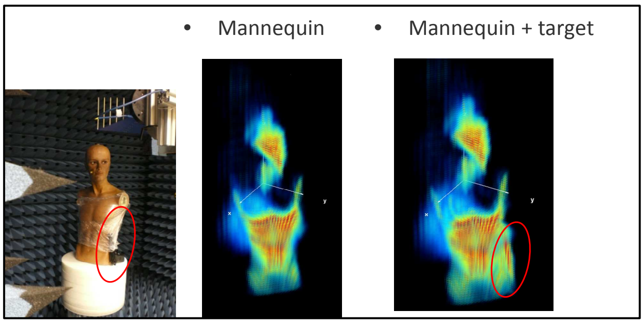

FIG. 6: Analysis example with a metallic gun as a target located on the side of the mannequin.

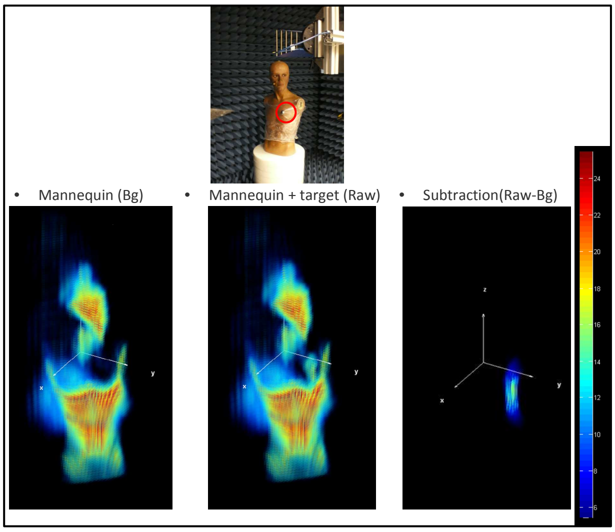

FIG. 7: Analysis example with a metallic ball as the target located against the trunk of the mannequin.

4.2 Imaging aspects

For the RF portal system (frequency below 20 GHz) developed in SAMOSA project, the detection of concealed weapons (handguns, knives, explosives) that can be worn by airline passengers is based on the use of images derived from a three-dimensional cylindrical imaging technique. The selected 3D cylinder configuration of the portal turns out to be well suited to the morphology of the human body. In addition, it allows acquiring a multi-view information of the screening person without requiring it to turn on itself as is the case with a planar configuration system. Compared with millimeter wave systems, cross-range sampling being less severe in RF frequency band, the data size to process is less important which allows releasing the constraint on the required computing power. In addition, the use of larger wavelengths produce "scattering centers" images that do not have the "almost photographic" appearance of images obtained with millimeter system which poses problems in terms of privacy.

The construction of the images is based on the inversion of the relation that connects the complex signal (amplitude, phase) returned by the object under test in near field E(f, θ, h) and its reflectivity σ(x,y,z) :

$$E(f,\theta,h)=\iiint_V \sigma(x,y,z)e^{jk(R_e+R_r)}\frac{dV}{R_eR_r}$$

R_e+R_r is the distance between each reflectivity element of the object and the antennas (transmitting and receiving), $k=2\pi f/c$ is the wavenumber associated with the electromagnetic field illuminating the object under test.

To avoid aliasing effects on the image, the scattering field by the object must be digitized with a sampling increment in frequency, angle and height which must satisfy the Shannon criterion:

$$df=\frac{c}{2*\sqrt{4*R_s^2+H_s^2}} \qquad d\theta=\frac{\lambda_{\min}\sqrt{R_s^2+r_p^2}}{4R_sr_p}$$

$$dh=\frac{\lambda_{\min}\sqrt{(H_s+h_p)^2/4+R_s^2}}{2(H_s+h_p)}$$

c is the speed of light, R_s and H_s are the radius and the height of the measurement portal, r_p and h_p are the radius and the height of the cylinder which include the body of the person.

Among the multitude of techniques that can be used to calculate the images, back projection method like the Direct-And-Sum algorithm offers a flexible usage and allows taking into account the near-field configuration effects (spherical illumination, attenuation in distance of the EM field). In addition, it can be easily associated with recombinant signals techniques and post-processing (cross-correlation, coherence factor) to improve the clarity of the images (notably the sidelobes level). Finally, in a real-time operating environment, this algorithm is naturally parallelizable. Before presenting some preliminary results, it is useful to recall that the response of most of the objects to detect (of less than 15 cm length) is in the resonant region when illuminated by RF signals. In this region characterized by a ratio between the size of the target and the wavelength of the EM signal comprised between 1 and 10, the main scattering mechanisms are surface wave (traveling wave, creeping wave) and optical interactions (specular reflection, diffraction). The geometric details of targets don't affect significantly their response.

During this year, imaging tests were performed on a hollow plastic mannequin (Fig. 8) filled with water and focused on the 0.8-12 GHz frequency range. The cylindrical configuration was performed with a turntable and a vertical rail (Fig. 4) on which a receiving and a transmitting antenna are placed. It is worth noting that the distance between the center of the turntable and the antennas is 70 cm and that the vertical scan of the antennas is 80 cm. In this frequency band, the image of the signal reflected by the mannequin consists of strong localized scatterers and do not clearly reveal its silhouette. For example, Fig. 9 shows a 3D mannequin image compressed to a 2D image using a maximum value projection obtained in VV polarization from a 112° angular domain centered around the front view and a frequency band between 0.8 GHz and 12 GHz.

FIG. 8: Mannequin alone.

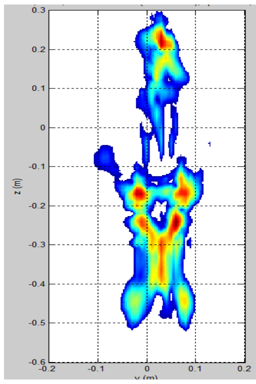

FIG.9: Mannequin image at 0.8-12GHz (maximum value projection).

Generally, and for most metallic or dielectric objects placed on the mannequin, the resulting image does not allow formal detection of their presence. However, if prior to the calculation of the image, the response of the mannequin is estimated using a sliding average angular method from the available measurements and is subtracted, detection becomes possible for a number of objects. Figure 11 shows the image of the response of the mannequin with two handguns (one plastic and one metal) (Fig. 10) illuminated with a RF signal between 2.7 GHz and 4.7 GHz in VV polarization. On the image, the two main echoes are localized at the same place as the handguns. Similarly, Figure 13 shows the result in the case of 2 low permittivity simulants of explosives of spherical (D = 50.8 mm) and cylindrical (D = H = 50.8 mm) shape placed on the mannequin (Fig. 12). The frequency band of the transmitted signal is between 8 GHz and 12 GHz. Again, we can see that the position of the 2 echoes coincide with the location of the explosives.

FIG. 10: Mannequin with 2 handguns.

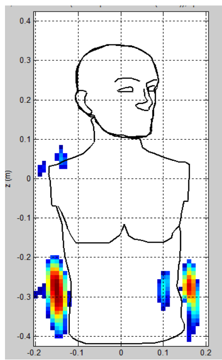

FIG. 11: Image obtained after removal of the response of the mannequin estimated by a sliding average angular method.

FIG. 12: Mannequin with 2 low permittivity explosives simulants.

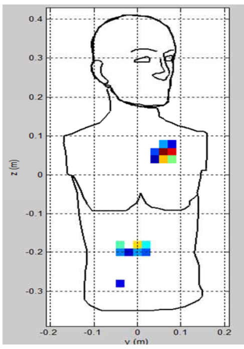

FIG. 13: Image obtained after removing the reflectivity of the mannequin by a sliding average angular method.

The activities carried out during this year were used to assess the interest to operate the lower part of the RF band. It turns out that in this band, the contrast between the targets and the body is not favorable to direct detection. In particular, the lowest band between 800 MHz and 2 GHz whose implementation is tricky (dimensions of the antennas, coupling, etc.) is not determinative. For higher frequencies, the implementation of a body's response elimination technique has allowed to obtain interesting results for certain types of targets.

In future work, the effectiveness of the body removal technique will be tested. We will also exploit higher frequencies (Ku-band) for which better direct detection is expected with a higher contrast between the response of the target and the body and also the presence of discriminating interactions (Fig. 14, Fig. 15). Finally, the coming year will also be the opportunity to exploit measurements on people obtained with the portal under development.

FIG. 14 : Dielectric sphere (ε_r=2.53, D=50.8mm)

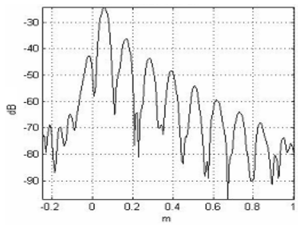

FIG. 15: Down range response (ku band, VV)

4.3 Technical developments

In parallel of the tests with the preliminary prototype and of the work on the imaging aspects, some technical activities are led in order to develop the subsystems that will complete the future demonstrator.

The first subsystem concerns the RF chains for emission and reception. The main difficulty will be to perform a very fast measurement. The FMCW technology has been chosen. The entire frequency band is divided in few narrow bands. A local oscillator YIG associated with multipliers allows generating the emitted signal. The reception RF chain is based on IQ mixers and a numerical receiver.

The second subsystem concerns the antennas arrays. The imaging algorithm criterion imposes to place an antenna every 2 centimeters. The main difficulties are then, to reduce the size of the antennas and to decrease the coupling between them. Some electromagnetic simulations and measurement campaigns on prototypes have been performed to develop the new innovative antenna arrays.

The following steps will be to integrate the subsystems together in order to build the demonstrator. This demonstrator will allow scanning in 3D a person carrying a potential target.

5. Conclusion

This study project presents an innovative and exhaustive approach for developing an airport radiofrequency scanner.

The acceptability and interacceptability aspects, the legal, ethical, health and societal aspects are studied in parallel of the technical developments.

The project presents important technical challenges. Technical developments are being led and will end in innovative solutions. A functional demonstrator will allow validating the technical solution on real persons.

This project is financed by the ANR in the frame of the CSOSG 2010 program. It has begun in March, 2011. The end of the project will take place on February 28th, 2015.

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